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On the geography of a worst case nuclear attack on the population of Britain

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ABSTRACT. By solving a special type of geographical location–allocation problem it is possible to identify an optimal set of demographic targets which approximately maximize the number of civilian casualties in the event of a large-scale nuclear attack on Britain. These worst case results can be compared with the far more optimistic casualty estimates prepared by government agencies for public consumption. Indeed, contrary to the popular belief promoted by the government, it seems that a large-scale nuclear attack aimed at population targets could kill over 80 per cent of the population. Yet the scale of the attack examined in the paper is realistic in that it is within the capabilities of the USSR, indeed it would be possible to combine this strategy with the bombing of purely strategic targets. Finally, it should be noted that the casualty estimates made here provide an assessment of only one hypothetical attack scenario and they may well be underestimates because of the simplifying assumptions that are made. Nevertheless, it is hoped that these results can be used in public debate as a basis for an honest and far-reaching reappraisal of the likely spatial impacts of a nuclear attack on Britain, with all the implications this holds for Home Defence planning and the debate about the continued possession of nuclear weapons.

Introduction

There is currently much speculation as to the possible consequences of a nuclear attack on Britain (Goodwin, 1981; Rogers *et al.*, 1981; Clarke, 1982). The subject is very topical because of the government's decision to site cruise missiles in Britain and its intention to spend between six and 10 billion pounds on a Trident submarine programme. In addition, the growing peace movement in Europe has drawn attention to the extraordinary dangers posed by the new generations of nuclear weapons, by a shift from a formal policy of deterrence towards a nuclear war-fighting capability, by the preparations being made for a limited or tactical nuclear war in Europe, by the likelihood that with the proliferation of nuclear weapon powers the arms race will become multiple arms races, and by the prospect that with large numbers of tactical nuclear weapons deployed in the field these arms races will become irreversible.

It is possible that political support for many of these developments is partly based on mistaken assumptions about the effects of nuclear weapons and nuclear warfare on civilian populations. It is certainly true that nuclear war is no longer being presented, as it once was, as an utterly catastrophic event and it is even being suggested that nuclear wars are survivable. Indeed various estimates have been made of the casualties likely to result from an attack on Britain. They are all highly uncertain and are dependent on a series of geographical variables including: the location of targets, the distribution of population at the time of the attack or attacks, and the prevailing weather conditions; as well as other factors to do with the assumed explosive yields of weapons, the locational accuracy of delivery systems, and so on. However, it is clear that many of the important variables have a spatial component to them so it is surprising, therefore, that the spatial aspects of nuclear warfare have not previously received more attention from geographers; an important exception is Bunge (1982).

Furthermore, while numerous computer studies have been made for attacks on the USA and USSR—for example, Office of Technology Assessment (1980), Drell and von Hippel (1976), Fetter and Tsipis (1981)—many of the estimates which have been made for Britain have been calculated by hand (Steadman, 1981), or assume average population densities, or employ simplified distance–density functions, or are limited in geographical scope (Haines, 1981). An important exception is the work by the Scientific Advisory Branch of the Home Office (Butler, 1982), although full details of their estimates have not been published.

The present paper is an attempt to remedy some of these deficiencies. It describes the results of a theoretical study which seeks to estimate the maximum number of casualties that could be caused by an attack directed specifically at the population of Britain. A computer algorithm is described that will identify an optimal set of population targets which maximize the numbers of deaths and injuries resulting from blast effects. Additional casualties resulting from the effects of thermal radiation and delayed fallout are not considered because it is very difficult to predict these effects and thus they would not normally be relied upon in target planning. The purpose of this exercise is to estimate approximate upper limits on the numbers of casualties so that these values can be compared with estimates derived by other means for different attack scenarios.

It might be objected that such an exercise, involving as it does an explicit 'city busting' or purely demographic targeting strategy, is not relevant to the military situation of the 1980s. Certainly, during the 1950s and 1960s, when the formal policy of deterrence by mutually assured destruction was at least theoretically in operation, large yield weapons were targeted at cities. A nuclear first strike was deterred by the prospect of unacceptable damage to cities and large numbers of civilian deaths caused in retaliation. Such a strategy was made necessary by the low accuracy of the available delivery systems. However, improvements in missile technology and guidance systems now make it practical to aim weapons of relatively low yield precisely at small military targets, such as missile silos; hence the move to counterforce or nuclear war fighting strategies in the early 1970s.

There are two further general considerations. It is likely that British cities would not be targets of the highest priority in a Soviet attack (Clarke, 1982, chapter 4). The

Soviets' first concern would be to destroy early warning systems as well as control and communications centres; and after that to attack military airfields and submarine bases in order to knock out the weapon systems which might be used in a counter-attack. However, there is some evidence to suggest that Soviet military doctrine does not mirror the official NATO policy of controlled or gradual escalation towards a full-scale nuclear war and that, instead, it aims at massive destruction in an all-out surprise attack. Furthermore, the scale of attack on Britain is assumed by several authors, including the Home Office, to be sufficiently large as to combine a comprehensive bombardment of likely military targets together with a large-scale assault on cities.

A second consideration concerns the theoretical distinction between counterforce or military targets and countervalue targets, such as cities and industrial areas. It is suggested that this distinction is an unreal one for a densely built-up country such as Britain. One has only to quote such examples as the proximity of the Polaris and Poseidon bases to Glasgow and Clydeside, the presence of naval bases and docks at Plymouth, Portsmouth, Southampton and Chatham, or the headquarters of RAF Strike Command at High Wycombe. Even precisely directed and relatively low yield weapons on these military targets would result in large numbers of civilian deaths.

This paper demonstrates, for that part of a comprehensive counterforce plus countervalue attack which is directed at cities, the worst possible outcome which could occur in terms of civilian casualties. It can provide a benchmark against which to compare casualty figures based on other scenarios, perhaps with mixtures of civil, industrial and military targets. The study also serves to pinpoint, in order of seriousness, the locations of those individual targets throughout Britain where casualties caused are most numerous (or would be if the population distribution at the time of the attack were the same as that on census night in 1971).

The effects of nuclear weapons

The standard text on the effects of nuclear weapons is by Glasstone and Dolan (1980), produced by the US Department of Defence and US Department of Energy. It tabulates the results gained from studies of the Japanese bombs, from the American programme of weapon tests, and from theoretical models. The Home Office also rely heavily on this book (Home Office, 1974, 1981). The critical data are also summarized in the form of a 'Nuclear Bomb Effects Computer', which is a circular slide-rule (Fletcher, 1977). An additional source is SIPRI (1981).

The principal effects can be classified according to their time scale. Immediate effects include the blast wave from the explosion which propagates through the atmosphere, the burst of thermal radiation and light, the initial nuclear radiation consisting mainly of neutrons and gamma rays, and the instantaneous pulse of electro-magnetic radiation which damages electronic equipment but is not directly injurious to people. All these effects occur within seconds or minutes of detonation. The most important medium-term effect is the radioactive fallout which is deposited over a period of days and weeks and is most dangerous during that time, although it can remain active over months and years. In the very long term all sorts of ramifying ecological and environmental consequences might occur, and the effects of radiation can induce cancers and genetic damage in the survivors.

The explosive power or yield of a nuclear weapon is measured by its energy equivalent in tons of TNT. The units used are kilotons or thousand tons equivalent (kt), and megatons or million tons equivalent (Mt). The bombs dropped on Hiroshima and Nagasaki had yields of approximately 13 and 22 kt respectively. Current Soviet strategic nuclear weapons have warheads in the range 150 kt to 20 Mt.

An important variable is the height above the ground at which the weapon is exploded. Bombs detonated at low altitude, such that the resulting fireball touches the earth, are referred to as ground-bursts. Those exploded at higher altitudes are air-bursts. For a weapon of a given yield, the effects of blast are more powerful at ground zero, and are concentrated in a smaller area, by a ground burst. Thus ground-bursts would be used to attack heavily protected targets such as missile silos, underground command centres, and nuclear power stations. A ground-burst scours large quantities of debris out of the resulting crater and carries them up into the radioactive cloud, to be deposited later as fallout. By comparison, the fallout produced by an air-burst is relatively minor. On the other hand, an air-burst exploded at an 'optimum' height will cause blast damage over the greatest possible area. Air-bursts might be used against large unprotected targets, such as oil refineries and cities.

Table 1 shows the areas of lethal damage from various nuclear weapon effects. By area of lethal damage is meant that area in which the estimated numbers of persons killed outside the zone equals the numbers of survivors inside the zone. It should be emphasized that these figures are extremely approximate and could vary widely under different conditions and assumptions. The table is used here merely to illustrate the general nature of nuclear weapon effects.

It should be noted that, for blast effects, the consequences of exploding the weapon as an optimal height air-burst is to more than double the lethal area by comparison with an equivalent ground-burst. In addition, the lethal area for initial radiation becomes progressively less significant by comparison with blast and heat, as the weapon yield increases. For weapons in the megaton range it can be ignored for the purposes of casualty assessment.

Notice also that the range of lethal heat effects extends over a much larger area than blast. However, these figures relate to distances at which people caught in the open in direct line of sight from the fireball would receive third-degree burns;

TABLE 1. Areas (km^2) of lethal damage for various nuclear weapon effects

Type of damage	*Explosive yield*				
	1 kt	*10 kt*	*100 kt*	*1 Mt*	*10 Mt*
Blast (ground-burst)	0.6	2.9	13.6	63	289
Blast (air-burst)	1.5	6.9	32.2	149	696
Heat	1.3	11.2	74.2	391	1583
Initial radiation	2.9	5.7	11.5	22	54
Fallout	3	15	180	1700	20 000

Source: Glasstone and Dolan (1980), SIPRI (1981).

without medical treatment these would be fatal. The blast figures by contrast refer to all persons present in the area, whether inside or outside buildings. The heat effects are also highly dependent on atmospheric visibility—in *Table 1* this is assumed to be 20 km. The numbers of resulting deaths are obviously related to the total number of persons out of doors and this can vary with time of day or night, the time of year, and the weather.

In a recent American study of an attack with a 1 Mt ground-burst bomb on Detroit, the numbers of blast casualties were calculated as 220 000 with 430 000 further blast injuries (OTA, 1980). By comparison, estimates of the numbers of deaths from burns among the survivors of blast effects ranged from 1000 for 3.2 km visibility and assuming 1 per cent of the population exposed to the fireball, to 190 000 for 16 km visibility and assuming 25 per cent of the population exposed. The numbers of injured but not killed by burns varied similarly between 500 and 75 000. It is clear from these calculations that, under the worst conditions, the numbers of deaths from burns might be of the same order as those from blast effects.

Finally, observe that the lethal areas from fallout shown for weapons in the megaton range are orders of magnitude greater than those for all other effects. The prediction of fallout patterns and the resulting casualties is a very complex matter. Once again the weather is important since the speed and direction of the wind determine the spread of the radioactive cloud. The wind speed assumed in *Table 1* is 24 km per hour. The pattern of precipitation also affects where the fallout reaches the ground. Most calculations assume that the fallout is deposited within an idealized series of elliptical contours corresponding to different dose rates, whereas in reality the pattern will be highly irregular and not predictable with any great accuracy.

The present study is concerned with maximizing blast effects and for this reason all the bombs are assumed to be air-burst with no fallout. Furthermore, no consideration is given to the possibility of burn casualties, although the prospect of additional casualties needs to be borne in mind.

The effects of blast can be represented by means of a simple model which consists of a series of concentric damage rings centred on ground zero. The shock wave from the explosion creates an overpressure, that is, a pressure in excess of normal atmospheric pressure, which rises to some maximum value as the wave passes a given point on the ground. These peak overpressures decline with distance from the centre and are measured in kilopascals (kPa). These forces act on the external and internal surfaces of buildings to explode or collapse them completely, or else at lower pressures to blow doors and windows in or out, strip tiles from roofs, etc. An overpressure of 35–40 kPa is sufficient to destroy the average brick-built house. Some damage to buildings will occur at overpressures of 7 kPa or lower. Most casualties are caused indirectly, through people being trapped under falling buildings, by their being propelled at speed into obstacles, or by their being hit by flying debris.

The total areas affected by blast damage are approximately proportional to the $\frac{2}{3}$ power of the yield of the weapon, so that an increase in yield by a factor of eight is needed in order to double the radius of the 7 kPa overpressure ring. The radii of the overpressure rings also depend on the height above ground at which the bomb is exploded. *Table 2* shows the comparative effects of 200 kt and 2 Mt weapons, both ground-burst and air-burst, at optimum heights so as to maximize the 34 kPa and 69 kPa overpressure radii. These estimates are applicable to level open areas with a standard sea-level atmospheric pressure. It is thought that the overpressure radii can be predicted with a reasonable degree of accuracy.

The conversion of overpressure figures into casualty estimates is far more uncertain. The model used here is that given by OTA (1980: 19). The assumptions are simply that: within the 83 kPa ring, 98 per cent die and 2 per cent are injured; within the range 34–83 kPa, 50 per cent die and 40 per cent are injured; within the range 14–34 kPa, 5 per cent die and 45 per cent are injured; and within the range 7–14 kPa, 25 per cent are injured. Beyond the 7 kPa ring no further casualties are assumed to occur. The OTA report describes these assumptions as relatively conservative. They are certainly more elaborate than the crude rule of thumb applied in *Table 1* where the lethal area is merely taken to be given by the 34 kPa radius from ground zero.

TABLE 2. Radii (km) of peak overpressure rings for specified yields

Yield	*69 kPa*	*34 kPa*
200 kt ground-burst	1.8	2.6
200 kt optimum height air-burst	2.6	4.0
2 Mt ground-burst	3.9	5.6
2 Mt optimum height air-burst	5.6	8.7

Source: Fletcher (1977).

What scale of attack is likely?

Another important variable is the scale of the nuclear attack that might be expected. At which targets would bombs be directed and what yields might these weapons have? Presumably, military estimates, and Home Office assumptions for the purpose of Home Defence planning, are based at least in part on restricted intelligence information. However, according to Clarke (1982) both American and British Home Office spokesmen have declared publicly that attack patterns cannot be predicted with any confidence. In any case it is thought that Soviet targeting policies are highly volatile. In the absence of any concrete information several different speculations are made.

It is possible to start from what is known about the total size of the Warsaw Pact arsenal, and then make estimates of the proportion of these weapons which might be targeted on, and reach, Britain in a war. These estimates can be guided by such information as has leaked out from, or has been released by, the Home Office on the attack scenarios devised for Home Defence exercises. Alternatively, it is possible to compile lists of likely targets from published sources together with plausible guesses about Soviet strategy and then add up the total megatonnage used.

It seems that the USSR currently possesses about 5000 strategic nuclear warheads, with a total explosive power variously estimated at between 5000 and 7500 Mt (Barnaby, 1980; Neild, 1981). These figures include medium- and long-range missiles launched from land and from submarines, and bombs carried by aeroplanes, but exclude short-range weapons intended for tactical use. According to official American sources the number of Soviet strategic warheads is expected to rise to over 8000 by 1985, with a total yield of 10 000 Mt (Congressional Budget Office, 1978). It further appears that, out of the current Soviet arsenal, some 2000–2500 warheads are deployed for use in the European theatre (International Institute for Strategic Studies, 1980; Kaldor, 1980). The IISS estimate that 800 of these warheads might reach their targets in a war.

Starting from this point, Goodwin (1981) has argued that, if these 800 warheads were divided among the countries of Western Europe in proportion to their populations, the results would be approximately 140 warheads for Britain. Goodwin suggests that the yields of these weapons might vary between 150 kt and 1 Mt or larger. Simply dividing the figures for total numbers of warheads by the total yield, as given previously, produces an average yield per warhead of between 1 and 1.5 Mt. One could also argue that, since Britain is a nuclear weapon power and also acts as a forward base for the US nuclear forces, it might well attract more than its fair share on the basis used by Goodwin. This is also broadly consistent with estimates made by the Home Office, who state that 'It is thought that in a nuclear war the UK might expect about 200 megatons of nuclear weapons of various sizes to be delivered against about 80 targets' (Home Office, 1981). Details of the 1980 Home Defence exercise, code-named Square Leg, serve to confirm this statement (Campbell, 1980, 1981). In that exercise it was supposed that some 125 weapons were exploded on some 100 targets, approximately half of which were countervalue or city and industrial targets. The total yield of the weapons was 200 Mt.

Similar figures are assumed for the purposes of some theoretical calculations of casualties resulting from an attack, made by the Home Office Scientific Advisory Branch, and reported in a recent paper (Butler, 1982). The paper summarizes the effects of attacks with 84 weapons totalling 181 Mt, and with 179 weapons totalling 193 Mt.

One further possibility is to compile lists of likely targets, assign numbers and yields of weapons to each, and add up the totals. Working in this way, and following the general strategic priorities which have actually been enunciated by Soviet military theorists, Clarke (1982) arrives at an attack pattern with 188 weapons totalling 167 Mt. Of these, counterforce and industrial targets account for 180 weapons and 127 Mt, and only a further eight bombs, albeit with a combined yield of 40 Mt, are assigned to cities. However, Clarke does point out that since the industrial targets include ports and power stations, and many military targets are near cities, it is to only otherwise untargeted cities that he assigns these last eight weapons.

These different assumptions are summarized in *Table 3*. The majority of opinion inclines to the view that an attack on Britain would be with weapons having a yield between 150 and 200 Mt. The individual yields of the bombs could vary widely, but the average might be between 1 and 1.5 Mt. There are several actual weapons in the current or planned Soviet strategic forces with yields in this range: for example, the SS-N-6 and SS-N-8 submarine-launched ballistic missiles with 1 Mt warheads, and the S-11 and SS-18 intercontinental ballistic missiles with 1.5 Mt warheads. Of this 200 Mt, at least 40 Mt according to Clarke, and perhaps up to 100 Mt according to Square Leg, might be directed specifically at cities, although numerous civilian casualties would also be caused by most of the remaining weapons.

TABLE 3. Estimates of the scale of attack by the USSR on Britain

Source	*Warheads*	*Targets*	*Total Mt*	*Average yield Mt*
Butler (1981)	84		181	2.15
	179		193	1.08
Campbell (1980, 1981) Square Leg	125	100	200	1.60
Clarke (1982)	188		167	0.89
Goodwin (1981)	140	114		
Home Office (1981)		80	200	

An algorithm for identifying a worst case bombing strategy

The principal geographical problem presented by this paper is how to identify an optimal set of demographic targets. The aim is to achieve a maximum number of direct casualties resulting from blast effects for a minimum number of weapon detonations. This can be viewed as a spatial modelling problem, a special type of location–allocation assignment problem. It is geographical in nature because of the need to identify optimal target locations for a fixed population distribution, given certain assumptions about weapon characteristics and a casualty estimation model. The results are conditional upon a number of critical assumptions concerning: the number and yield of the available weapons, the accuracy and reliability of the delivery systems, the height of the explosions, the nature of the ground-level topography, and the distribution of population at the time of attack.

The geographical optimization problem is easily solved. The following algorithm is used to identify optimal target locations for a given set of weapon and weapon effect assumptions.

Step 1

Britain is approximated by a rectangle of 1030 km from north to south and 655 km from west to east. The consequences of a nuclear weapon detonation are estimated for the mid-point of each 1 km grid-square within this rectangle. It is assumed that all the warheads have a yield of 1 Mt and are air-burst at a height of 1830 metres, which maximizes the ground area within the 206 kPa overpressure ring. This is a conservative assumption since larger numbers of casualties could have been obtained by utilizing a height which optimized the 34 kPa radius. The radii for the 83, 34, 14 and 7 kPa overpressure rings are determined from Glasstone and Dolan (1980). The respective radii are 3.7, 6.4, 10.6 and 16.7 km from ground zero. Deaths and injuries are calculated using the OTA (1980) casualty model described earlier. The population data used for these calculations are the 1 km grid-square population data from the 1971 census. Populations for squares dissected by the distance bands are estimated under the assumption of a uniform population distribution within each square.

This preliminary stage of the algorithm sets up a bomb-population data-base by repeatedly applying the simple centrographic blast and casualty model described previously. Computer run times were greatly reduced by the application of a fast spatial data retrieval algorithm, see Openshaw (1982) for details. Nevertheless, computer run times amounted to about one hour of CPU time on an IBM 370/168 computer.

Step 2

The bomb-population data-base is searched to identify the 1 km square with the highest number of casualties.

Step 3

The population data are now updated by subtracting deaths from the base population. The bomb-population data-base is also updated by recomputing potential casualties for all the 1 km squares affected by the assumed detonation in the square identified in Step 2.

Step 4

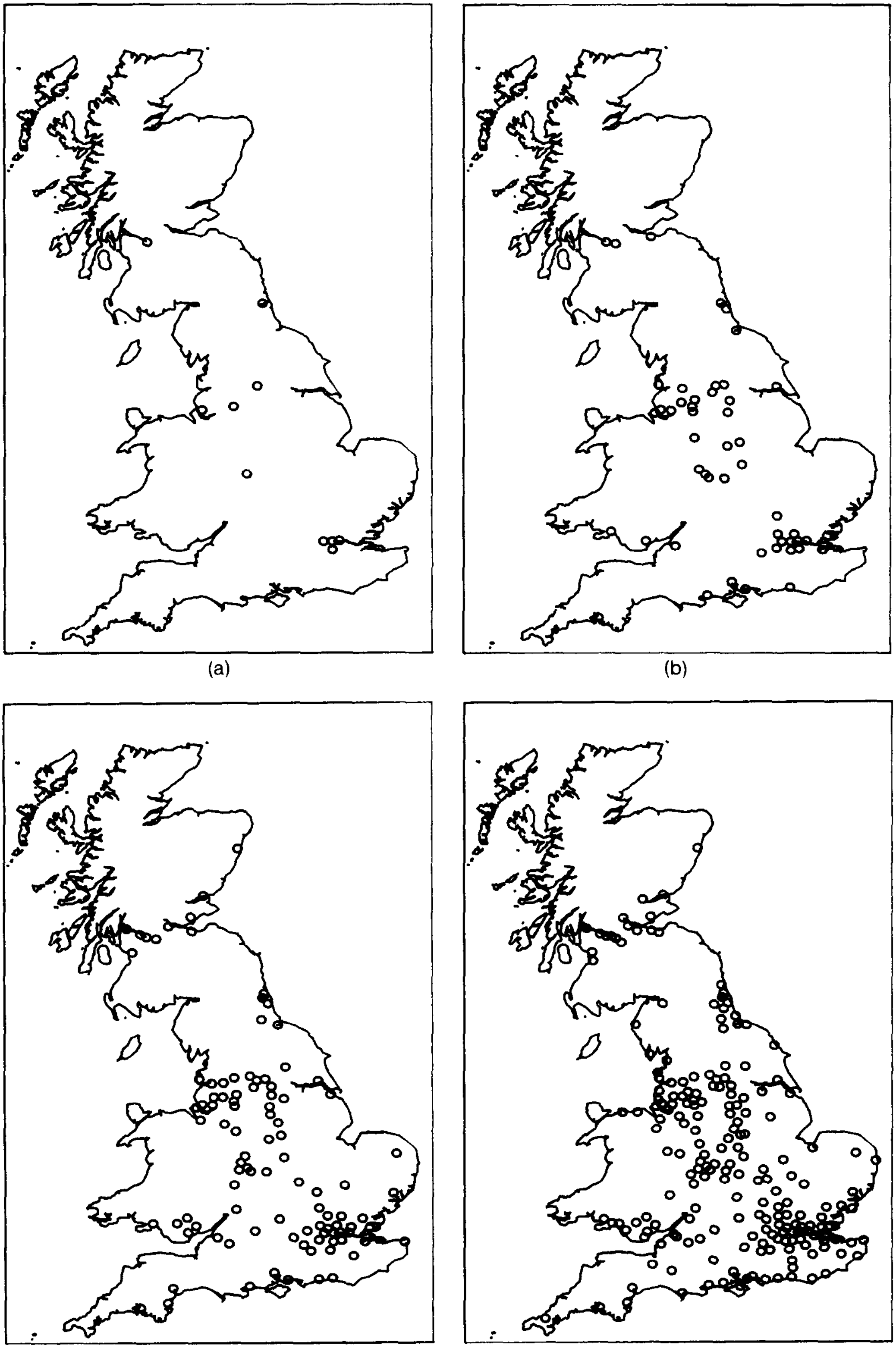
A bomb counter is incremented and the program either returns to Step 2 to find the next worst target or the run is terminated. Computer run times for 200 bombs were approximately two hours of CPU time on an IBM 370/168.

The sequential nature of the algorithm is of no real consequence since if all the targets were attacked simultaneously the overall result would be the same. One deficiency, however, is that the combined effects of several neighbouring detonations, either simultaneously or separated in time, might be greater than the sum of the independent explosions. For example, the blast waves from two bombs might interact in complex ways; damaged buildings might collapse with a second detonation at far greater distances than assumed in the blast model; and people forced out of buildings into the open by the first bomb might be more susceptible to injury from the second. These effects could in principle be taken into account by a subsequent run through the survivors, but there are no available data on which to base any estimates of additional casualties.

Results

Two complete runs are reported here. In the first run it is assumed that all the injured die, due to lack of medical facilities; this is the usual assumption that would be made (SIPRI, 1981). *Figure 1* identifies the target locations in order of seriousness for 10, 50, 100 and 200 weapon detonations. The circles represent a radius of 16.7 km. *Table 4* shows the relationship between the number of bombs and cumulative casualties. The results largely speak for themselves. A 200 Mt attack would kill outright a large proportion of the 53.949 million population of Britain.

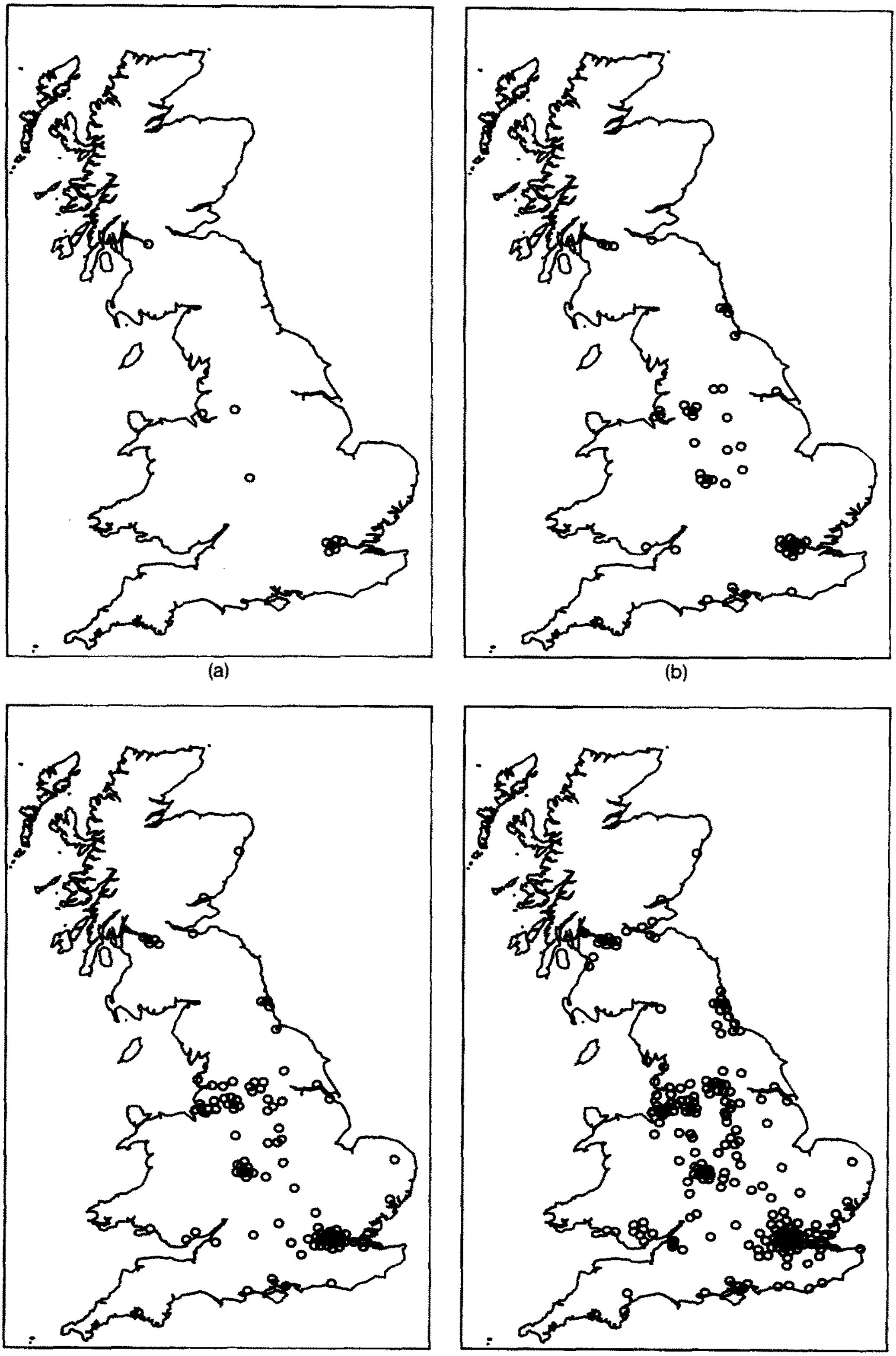
The first and worst bomb is dropped on Central London. It would kill and seriously injure approximately three million people. Furthermore, the next six bombs would each kill more than one million people: the targets being, respectively, Birmingham, Manchester, east London, Glasgow, Liverpool and west London. With 50 Mt approximately half the population of the country become



(a) (b)

(c) (d)

FIGURE 1. Target locations for maximum civilian casualties, assuming all the injured die: (a) 10 bombs; (b) 50 bombs; (c) 100 bombs; (d) 200 bombs.



(a) (b) (c) (d)

FIGURE 2. Target locations for maximum civilian casualties, assuming all the injured survive: (a) 10 bombs; (b) 50 bombs; (c) 100 bombs; (d) 200 bombs.

casualties. There is, however, a law of diminishing returns by which later bombs dropped on ever smaller cities and towns cause progressively fewer casualties. Thus the last 50 bombs, bomb numbers 150–200, cause only slightly more deaths than the first bomb.

The results of a second run are reported in *Figure 2* and *Table 5*. Here it is assumed that all the injured survive. If the results in *Table 4* reflect a slightly pessimistic assumption, then the results in *Table 5* represent a highly optimistic one. Yet a 200 Mt attack still manages to kill outright 33.1 million people, compared with 43.3 millions for the first run. However, this is not really much of an improvement, since about half the survivors could be seriously injured. The target pattern is now much more concentrated, with repeat bombing of the larger cities being necessary to ensure a maximum level of casualties.

TABLE 4. Worst case casualties, assuming seriously injured die

Bomb number	*Deaths (10^6)*	*Cumulative deaths (10^6)*
1	2.938	2.938
2	1.241	4.180
3	1.231	5.411
4	1.209	6.621
5	1.062	7.684
6	1.034	8.719
7	1.006	9.726
8	0.777	10.503
9	0.763	11.260
10	0.702	11.969
15	0.538	14.811
20	0.443	17.156
30	0.345	20.967
40	0.295	24.102
50	0.249	26.749
100	0.125	35.113
150	0.079	40.004
200	0.055	43.307

TABLE 5. Worst case casualties, assuming all injured survive

Bomb number	*Deaths (10^6)*	*Cumulative deaths (10^6)*
1	1.112	1.112
2	0.785	1.898
3	0.643	2.541
4	0.597	3.138
5	0.554	3.693
6	0.536	4.229
7	0.526	4.755
8	0.524	5.280
9	0.477	5.757
10	0.415	6.173
15	0.362	8.031
20	0.325	9.748
30	0.258	12.570
40	0.224	14.982
50	0.193	17.023
100	0.117	24.576
150	0.085	29.458
200	0.062	33.149

Discussion of the results

These results are of course a product of a number of assumptions that are built into the calculations. The census data relate to the night-time distribution of population in 1971; the 1981 population data for 1 km squares are not yet available. It is possible that bombs dropped on city centres during working hours on weekdays would result in more casualties, because of the concentration of office and shop workers, although it would be difficult to measure this effect because of the lack of small area data for day-time populations. Furthermore, if there were warning of an attack then it is conceivable that large numbers of people would try to leave the cities in search of what they might hope to be a safer refuge in the countryside. On the other hand, there are currently no official plans for mass evacuation as there were in the 1960s. Indeed the Home Office has a 'stay-put' policy (Butler, 1982) which it emphasizes with the warning 'If you move away . . . the authority in your new area will not help you with accommodation or food or other essentials' (Home Office, 1980). Evacuation plans exist only for medical staff and emergency services.

An attack with the same total megatonnage but divided into smaller or larger numbers of weapons with yields differing from 1 Mt would give different results. In addition the blast model is an ideal approximation which relates only to flat ground at sea-level atmospheric pressures. It is currently impossible to predict the effects of topography without access to a detailed topographical data-base for the entire UK. The pattern of attack also assumes that all the weapons reach and hit their optimal targets. The accuracy of aim of a given type of missile is conventionally expressed by a 'circular error probable' (CEP) which is defined as the radius of a circle with the target at its centre inside which the missile has a 50 per cent probability of landing. Many Soviet missiles have CEPs of the order of 500 metres (SIPRI, 1981, table 4). Since the population data are represented by 1 km squares the effects of introducing missile inaccuracies will not be great whilst the effects of missile failure cannot be predicted.

One factor that could influence casualty rates is the possibility that, given warning of an attack, the owners of purpose-built shelters would take refuge in them. Other householders might take the advice given by the Home Office (1981) and build improvised shelters in their gardens. However, these latter shelters offer protection only against 10 kPa overpressure. This is the pressure range for which the OTA report assumes 25 per cent injuries and no deaths. Thus, even if large numbers of people were to build such shelters, and this is doubtful, the effect on total casualties would be small. The shelter designs are principally intended to offer some protection against fallout. As for purpose-built blast shelters, these would offer protection against all but the highest overpressures. However, there is no government programme to build such shelters for civilian populations. Indeed the Home Office estimate that it would cost eight billion pounds to provide shelters for the 25 per cent of the population it thinks are most at risk.

More generally, it must be again emphasized that any weapon effects model must be an extreme oversimplification of what is in reality a highly complex and unpredictable event. Glasstone and Dolan (1980) write in their Preface:

> We should emphasise, as has been done in earlier editions, that numerical values given in this book are not—and cannot be—exact. Apart from the difficulties in making measurements of weapon effects, the results are often dependent upon circumstances which could not be predicted in the event of a nuclear attack. Furthermore, two weapons of different design may have the same explosive energy yield, but the effects could be markedly different.

In a similar warning about the difficulties of predicting the consequences of nuclear war, Rotblat makes a telling point about the two bombs dropped on Hiroshima and

Nagasaki (SIPRI, 1981). They were of comparable yield, both were air-burst, and dropped on cities of similar populations; yet the smaller yield bomb on Hiroshima produced twice as many casualties as that on Nagasaki. Furthermore, counts of the numbers of people killed and injured in the two explosions, made variously by American and Japanese authorities, differ by a factor of two (see Committee for the Compilation of Material on Damage Caused by the Atomic Bombs in Hiroshima and Nagasaki, 1981). As Rotblat says:

> Thus, even in the only instance in which nuclear weapons were employed against a population, an event which was subsequently investigated very thoroughly, large uncertainties remain about the absolute numbers of casualties . . . How much greater must be the uncertainty in a hypothetical war! (SIPRI, 1981: 105)

Until there is a far larger quantity of empirical evidence, it will be impossible to resolve these levels of uncertainty. It is claimed, however, that this study is no better and certainly no worse than other studies in this field (Butler, 1982).

Despite these problems it is nevertheless useful to compare the results obtained here with those reported by other authors. Haines (1981) studied the possible consequences of the Square Leg scenario on the Greater London area, using 1971 populations for 1 km squares and the OTA blast casualty rates. However, these results are not entirely comparable since the Square Leg exercise only envisaged an attack around the suburbs of the city, not in the centre, and involved five weapons totalling 11 Mt. Haines estimates 1.1 million deaths and between 2.4 and 2.9 million injured. The results obtained here are 7.3 million deaths if all the injured die, or 5.5 million if they all survive, for 11 Mt attacks. Erskine (1981) uses average population densities to estimate 0.326 million deaths for a 1 Mt air-burst on Bristol. The values obtained here are 0.545 and 0.362 millions depending on whether the injured die or survive.

Most directly comparable to the research described here is the work of the Home Office Scientific Advisory Branch, as reported by Butler (1982). Butler describes a computer model for estimating casualties with workings that are essentially similar to those used here. The principal differences are the blast and casualty model, and the fact that the Home Office program requires a list of targets and cannot find optimal targets on the basis of the numbers of resulting casualties. Butler describes a sample run for an attack that consists of 129 air-burst weapons totalling 84 Mt and 50 ground-bursts totalling 109 Mt—193 Mt in total. The resulting blast casualties were calculated as 16 million dead and 3.5 million seriously injured. This is clearly a very different conclusion from that indicated here in *Tables 4* and *5*. There are two obvious factors contributing at least in part to this difference. The Home Office scenario assigns more than half its total yield to ground-burst bombs, which reduce blast casualties whilst increasing fallout. Furthermore, the assumed targets are mainly military, although the scenario is said to include city targets. How many and which cities is not specified. It is likely that these might not be worst case targets of the sort identified here.

There are also other factors, which have to do with the Home Office underestimating the seriousness of weapon effects. For instance, the radii of the overpressure contours for air-burst bombs (Butler, 1982, figure 4) are significantly lower than the equivalent values given in Glasstone and Dolan (1980). The Home Office casualty rates are also lower than those used by OTA (1980). However, Butler does describe a second run with the same targets and weapon yields but with a more severe blast criterion (Butler, 1982, figure 10). In this case the resulting deaths from blast effects rise to 25 million.

A final consideration is that all these casualty estimates refer to only one of the causes of death and injury from nuclear weapons. Not only must the additional burns casualties from thermal radiation and fires and radiation sickness from fallout be taken into account, but there would also be various synergistic effects resulting from the combination of injuries and sickness from different causes. Beyond these there might be other risks to life and health which are even more difficult to quantify; for example, epidemics, radioactive contamination of food and water, the breakdown of law and order, etc.

Conclusions

It is difficult to escape the conclusion that an attack on Britain on the scale which is being seriously discussed would leave very few survivors. For most of the population, nuclear wars are not survivable. This suggestion would of course be hotly contested by those who seek, for political reasons, to argue the opposite. Nevertheless, it is important that governments and politicians face up to the realities of a large-scale nuclear attack on Britain, and refrain from the cruel deception that Home Defence planning will ensure the survival of most of the population.

Compared with the vast size and low population densities of the USA, the USSR or China, the geography of Britain is most unfavourable to the consequences of a nuclear attack. Perhaps only West Germany is in a comparable situation. A highly concentrated urban population, a relatively small land area, a large number of prime strategic targets, the general absence of civilian blast and fallout shelters, and the close proximity of home and workplace makes Britain highly vulnerable to the effects of a nuclear attack. It is difficult to imagine any sufficiently important excuse for a 'defence' policy that could, albeit under unlikely circumstances, justify the virtual extinction of the entire nation in the name of freedom and human rights.

The worst case bombing strategy described here demonstrates the vulnerability of the population of Britain to a large-scale nuclear attack. The values in *Table 4* and *5* provide approximate upper estimates of blast casualties. When governments make decisions about defence policies they should think realistically about the possible consequences of their actions on the population as a whole. While it is impossible to know in advance precisely which targets might be attacked and what casualties may be produced, nevertheless, it is possible to speculate as to the likely outcome. The effects of a large-scale attack on Britain would be utterly devastating. It is quite wrong for democratically elected governments to pretend otherwise and to seek to deliberately mislead their populations, for purposes of short-term political expediency, by presenting conclusions based on highly optimistic casualty estimates. Instead of being kept secret, the computer models, assumptions, and lists of prospective targets should be published in full so that independent experts and interested citizens could scrutinize them. Indeed, we would have wished that there was no need for this paper; but at present there appears to be a very urgent call for independent estimates of the effects of nuclear attack scenarios in order to introduce a greater degree of realism and rigour into the public debate. In so far as this is a spatial problem, then geographers should be doing their best to draw attention to the more geographical aspects.

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